FAIRS Experiment: Fluxes, Air-Sea Interaction, and Remote Sensing

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LONG-TERM GOALS

The goal is to determine the influence of microscale wave breaking on large-incidence angle radar backscatter and air-sea fluxes of heat, gas, and momentum.

OBJECTIVES

The objective is to perform a multidisciplinary, multi-investigator field experiment to demonstrate the potential for significant progress in air-sea interaction research through the collaboration of investigators in remote sensing, marine meteorology, and physical oceanography.

APPROACH

The FAIRS experiment took place aboard R/P FLIP from 15 September to 15 October 2000 approximately 120 nautical miles off Monterey, California. Our approach was to use both the passive and the active infrared techniques to determine the extent to which our laboratory findings are relevant to the field. Over the past several years, we have used these techniques to investigate wave breaking on spatial scales ranging from microscale breaking waves (0.1 to 1 m length) to large scale breaking waves, or whitecaps (1 to 100 m). When a cool skin layer is present, the wake of a breaking wave appears as a region of increased temperature because turbulence generated by the breaking process mixes warm water from below to the surface. As the turbulence decays, the cool skin layer reestablishes. The rate of recovery has been shown to depend on the strength of the turbulence that created the disruption as well as the net heat flux.

The Controlled Flux Technique (CFT) is an active technique in which a small patch on the surface is momentarily heated with a CO_2 laser. As with the recovery of the cool skin, the rate of decay of the heated patch depends on the turbulence and net heat flux. The local heat transfer velocity, k_{heat}, can be inferred from the rate of decay of the patch temperature. The active technique has the advantage over the passive technique that it can be used regardless of whether or not a cool skin layer is present.

Two main topics for analysis are planned for the data from the FAIRS experiment. The first topic is to use the CFT to investigate modulation of the skin temperature by wave breaking. The application is the influence of microscale breaking waves on large incidence angle radar backscatter and turbulent dissipation by large scale breaking waves. The footprint of the Ku-band scatterometer mounted on the face boom was co-located with the area in which the active infrared imaging technique was implemented. An infrared radiometer was aligned with the imager and a sonic height meter was mounted at nadir incidence over the same spot. Since the CO_2 laser used in the active IR technique was

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14. ABSTRACT

The goal is to determine the influence of microscale wave breaking on large-incidence angle radar backscatter and air-sea fluxes of heat, gas, and momentum.

15. SUBJECT TERMS

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pulsed at approximately 1 Hz, there are several samples of the decay rate distributed over the phase of the swell waves. The modulation of the decay rate will be used as a measure of the modulation of wind wave breaking by the swell waves. The result will be compared to the radar cross section modulation measured by Bill Plant at APL-UW. We will also investigate the use of the active IR technique to quantify the turbulent dissipation due to large scale breaking waves by comparing the decay rate in the background to that in the turbulent wakes left behind by a breaker. Graduate student Ruth Fogelberg at APL-UW is working on the analysis of large-scale breaking for her MS degree.

The second topic is the correlation between the average decay rates and the flux of heat and momentum measured from the port boom. The results will be examined in the context of surface renewal theory with emphasis on separating the dependence on wind stress from that on sensible and latent heat flux. This effort is in collaboration with Wade McGillis and Chris Zappa at WHOI, who made the flux measurements during FAIRS.

WORK COMPLETED

The FAIRS experiment was completed in October, 2000. Environmental data has been surveyed and an analysis strategy emphasizing the two main areas of interest listed above has been developed. The active IR data during the night have been processed using a preliminary algorithm.

RESULTS

Figure 1 shows times series of wind speed, significant wave height, and air and sea temperature.

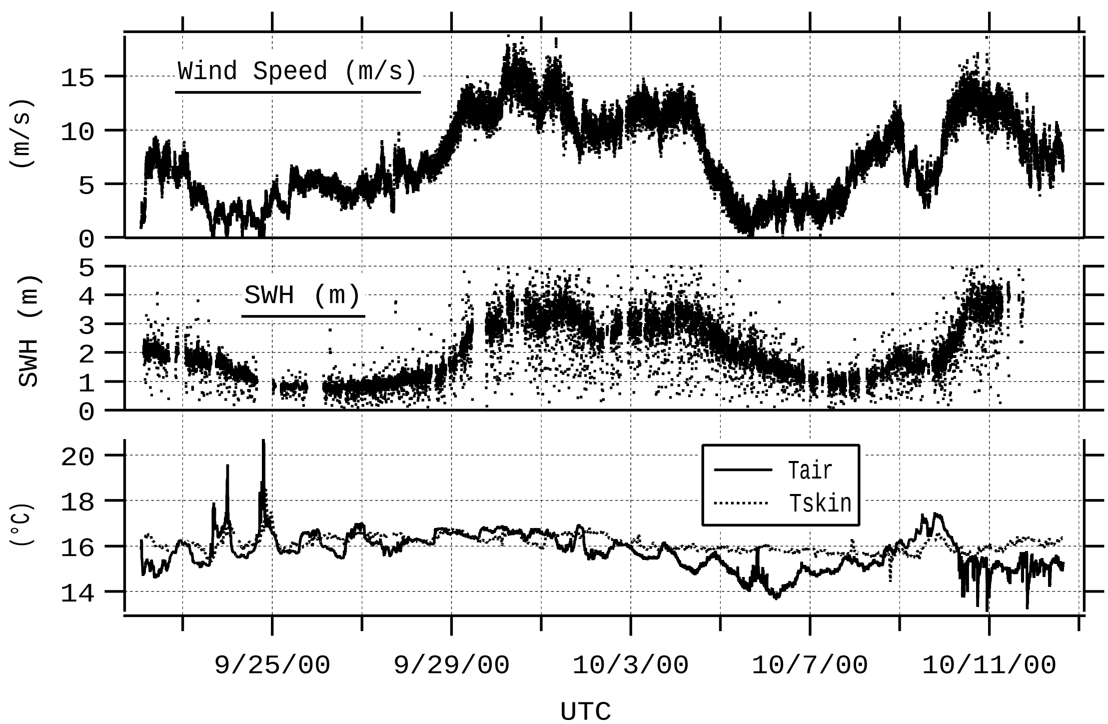

Figure 1. Graph of 21-day time series of environmental data from FAIRS experiment. The wind speed ranged from calm to greater than 15 m s^{-1}, the significant wave height ranged from 0.5 to 4 m, the air temperature ranged from 14 to 20 °C, and the water temperature was nearly constant at 16 °C.

During the 20 days of measurements, there were two calm periods with wind speeds below 5 m s^{-1} and two heavy weather periods with wind speeds above 15 m s^{-1}. The significant wave height ranged from less than 1 m to greater than 4 m. The water and air temperatures remained remarkably constant, resulting in conditions near neutral stability.

Under low wind speed conditions, the presence of a cool skin layer provided the opportunity to record the passive IR signature of microscale breaking waves. At the higher wind speeds under the near-neutral stability conditions present, the temperature difference across the skin layer was too small to allow passive detection of breaking events. The active IR method allowed us to impose a temperature difference at regular intervals along the phase of the waves passing by. The technique provides a method to measure k_{heat} at different locations relative to an individual breaking event. The modulation of k_{heat} along the phase of the wave can be used as an indication of the change in surface turbulence caused by individual breaking events over a wide range of scales. By averaging the local k_{heat} over many waves, we can also measure an average k_{heat}, which should correlate with the net heat flux measured directly by other investigators.

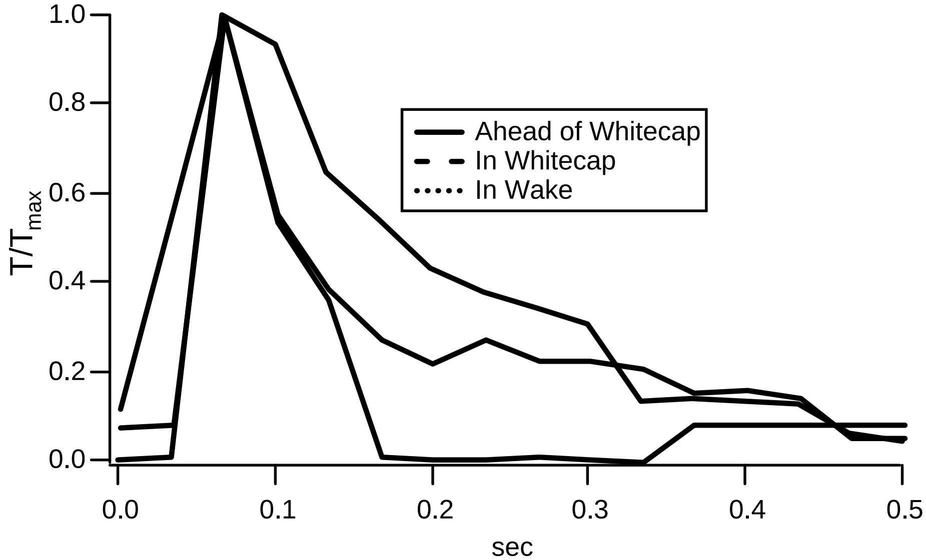

Figure 2. Field Measurements from FAIRS of decay curves for heated patch laid down at locations relative to the actively breaking crest shown in Figure 3. The decay is slowest in front of the crest, fastest in the active whitecap, and intermediate in the wake, after the crest passes. This variation with the level of turbulence suggests that the technique may provide a method to remotely measure dissipation.

Measurements using the active technique during the passage of a whitecap demonstrate the capability of the k_{heat} to provide information about breaking in the field. Figure 2 shows normalized temperature decay curves relative to the passage of a whitecap taken when the wind speed was 13 m s^{-1}. The longest decay time occurs for the heated patch measured ahead of the whitecap, before the patch is influenced by the breaking. This level of turbulence might be considered to be a background value to which turbulence generated by an individual breaking wave would be added. The shortest decay time corresponds to the rapid mixing that occurs when the spot is laid down right in the actively breaking crest. The decay time for the heated patch that is in the wake, after the whitecap passes, is intermediate between the other two. This intermediate decay time is the result of the turbulence generated in the wake. This example shows that the CFT can be used to quantify breaking in the field in a manner similar to that in the laboratory.

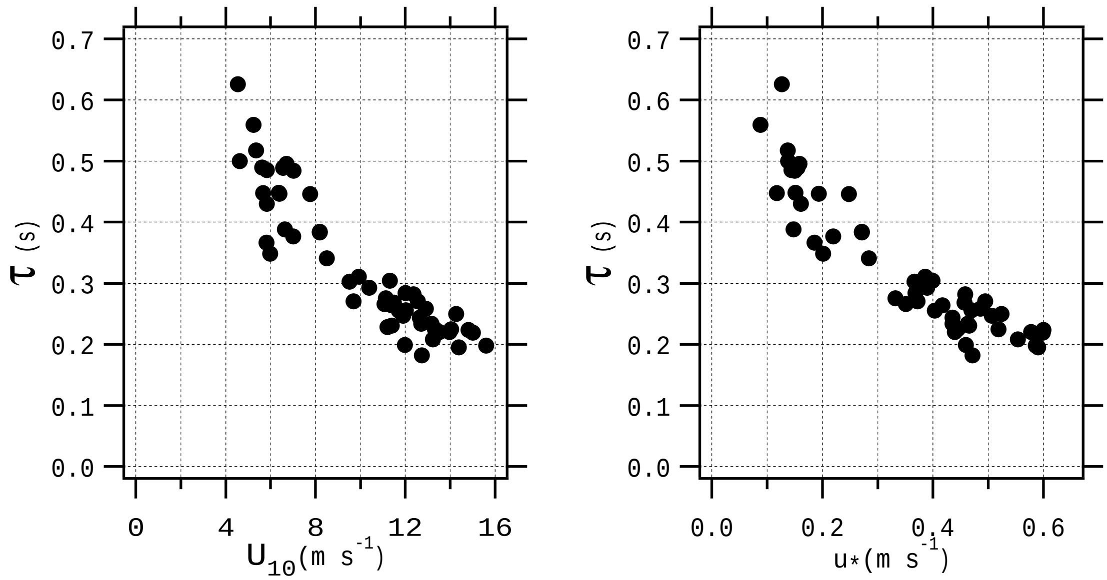

Figure 3. Wind speed and friction velocity dependence of the decay time τ, which is the time for spot temperature to reach one third of its maximum. Each point represents the average for a 5 minute record. The decay time decreases monotonically with both parameters.

Figure 3 shows the average patch decay time τ as a function of wind speed and friction velocity for wind speed ranging from 4 to 16 m s^{-1}. Each point represents the average of 300 pulses at 1 Hz over a 5-minute record for nighttime data only. The plots show that τ decreases monotonically with both wind speed and wind stress.

IMPACT/APPLICATIONS

This extensive suite of complimentary measurements provides a unique opportunity to demonstrate the potential of cooperative research in air-sea interaction through combining resources and expertise from remote sensing, marine meteorology, and physical oceanography. These are the first extensive field measurements using the CFT and they demonstrate the potential for the technique to provide remote measurements of turbulent mixing due to wave breaking over a wide range of scales.

RELATIONSHIP TO OTHER PROGRAMS OR PROJECTS

In addition to the ONR-funded collaborations with the investigators listed above, this work is related to a collaborative effort with Dr. W. E. Asher (APL-UW) to determine the role of microscale wave breaking in air-sea gas transfer funded by NSF.

PUBLICATIONS

Jessup, A. T., and W. E. Asher, “FAIRS Experiment: Fluxes, Air-Sea Interaction, and Remote Sensing,” IGARSS 2001, Syndey, Australia.

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Zappa, C. J., W. E. Asher, A. T. Jessup, “Microscale wave breaking and air-water gas transfer,” *J. Geophys. Res.*, *106*, 9385-9391, 2001.